Human and Environmental Health Issues Related to Use of Radio Frequency Chaff

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Radiofrequency (RF) chaff is an electronic countermeasure designed to reflect radar waves and obscure planes, ships, and other assets from radar tracking sources. Chaff consists of aluminum-coated glass fibers (also referred to as dipoles) ranging in lengths from 0.8 to 0.75 cm. Chaff is released or dispensed from military vehicles in cartridges or projectiles that contain millions of dipoles. When deployed, a diffuse cloud of dipoles is formed that is undetectable to the human eye. Chaff is a very light material that can remain suspended in air anywhere from 10 minutes to 10 hours and can travel considerable distances from its release point, depending on prevailing atmospheric conditions (USAF 2001). Training for military personnel, particularly aircraft pilots, in the use of chaff is necessary to deploy this electronic countermeasure effectively. As with most acquired skills, the deployment of chaff must be maintained by practicing in-flight release during training. It is estimated that the U.S. Armed Forces dispense about 500 tons of chaff per year (USAF 2001), with most chaff being released during training exercises within the continental United States.

Concerns have been raised since the early 1950s by both the public and government officials on the potential impacts of chaff on the environment. In response to these concerns, the Department of Defense (DOD) has sponsored or conducted research to address issues related to the use of chaff by the military including: (a) questions on its persistence and fate in the environment, (b) the effects of chaff on human, livestock, and wildlife health, and (c) the impact of chaff release on natural and cultural resources (GAO 1998, Hullar et al. 1999, USAF 1997, Cataldo et al. 1992, National Guard Bureau 1990, USAF 1978, Systems Consultants 1977). In this review, we address the historical and current use of chaff, the importance of its use in training and the effects of chaff on humans and the environment.

History and Use of Chaff

RF chaff was first used as a radar countermeasure in December 1943 by U.S. bombers flying over Bremen, Germany. At this time, chaff consisted of solid aluminum pieces of non-specific sizes that were tossed from cockpit windows or dropped from trap doors on the underside of bomber aircraft. Tactics of the time were to generate huge chaff plumes to provide slow-moving bombers with some protection against ground-based anti-aircraft fire.

Chaff technology has evolved considerably since World War II. Modern chaff is composed of glass fibers coated with a 3 μm-thick layer of high purity (99%) aluminum, which gives chaff its radar-reflective properties (Figure 1). Chaff fibers are approximately 60% glass and 40% aluminum by weight. Lead was used as a weighting material in early versions, but this metal is no longer incorporated into chaff (GAO 1998, USAF 1997). Chaff fibers are also coated with a lipid to prevent clumping. Modern chaff is cut to specific lengths that correspond to one-half the wavelength of specified radar bands. Along with chaff, "chaff debris" is also dispensed during the release of chaff. Typical chaff debris includes paper, cardboard, styrene plastic caps, pistons, and miscellaneous plastic parts.

Chaff is typically deployed in cartridges or projectiles, but can also be dumped or tossed from military vehicles. Chaff cartridges typically contain up to 100 million chaff fibers or dipoles (GAO 1998, USAF 1997). Training cartridges used by U.S. Navy aircraft contain about 5 million dipoles per cartridge (Hullar et al. 1999). Zuni rockets, used by the Navy to screen surface vessels from radar, contain about 8.5 pounds of chaff. Mortars are also used to launch chaff from ships and these projectiles contain up to 24 pounds of chaff. The Army will be capable in the near future of deploying over 300 pounds of chaff within 10 minutes to hide ground units from radar detection.

Current DOD Chaff Use Policy and Initiatives

Currently, DOD severely restricts the use of chaff in training in order to reduce pollution of the environment and to protect civilian airspace. At the height of the Cold War, training with RF chaff was permissible at all military training ranges and MOAs within the United States. Since 1990, the DOD has attempted to balance the chaff training needs of the Armed Services with concerns of the public and government for the possible negative impacts of chaff use on the environment. In 1998, the Joint Chiefs of Staff issued a directive incorporating chaff use policies of each of the Armed Forces and placed significant restrictions on the use of chaff for training in the United States (CJCSM, 1998). As a result, the number of training sites where chaff training is permitted has been reduced to approximately 50 selected ranges and MOAs in and around the US (see Fig. 2). Additionally, flight rules were changed and now stipulate that chaff should not be released below certain altitudes during training to ensure chaff plumes are widely dispersed and dipole ground level concentrations are very low. Likewise, DOD policy for chaff operations requires that every effort be made to conduct chaff drops away from major air routes and air route hubs and to avoid frequent dispersal over the same ground points. DOD policy also specifies that all planned chaff releases and training flight plans be reported to the Federal Aviation Administration and local environmental agencies.

In addition to making extensive policy changes in chaff use, DOD has initiated several cooperative relationships with Department of Interior (DOI) agencies aimed at minimizing the impact of chaff on public lands. Among these efforts is a committee formed between the DOD and the Bureau of Land Management to periodically evaluate the chaff deployment policies of each of the Armed Services for training conducted over public lands (GAO 1998).

Environmental Fate and Impact

Intact chaff fibers do not pose an inhalation risk to humans; however, degradation of the fiber might result in reduction to a size amenable to respiration and this is discussed further below. As such, degradation of chaff fibers under various environmental and mechanical conditions has also been of interest. The abrading of chaff dipoles to respirable diameters during pyrotechnic discharge or by weathering has been an issue of concern expressed by various parties (Hullar et al. 1999). The USAF found no evidence that chaff dipoles are abraded to respirable particulate during pyrotechnic discharge under controlled conditions (USAF 1997). Further studies are needed to definitively determine whether respirable chaff dipoles are released or formed in the process of dispersal.

Because of its large diameter relative to other particulate contaminants, chaff does not add to particulate matter (i.e., PM_{10} or $PM_{2.5}$) emissions as defined by the EPA. To understand what affect chaff may have on human health, Hullar et al. (1999) assumed that chaff degraded into PM_{10} and $PM_{2.5}$ and estimated the contribution of chaff to the respirable fractions. In their estimates, chaff would account for less than 0.25% of the particulate emission measurements for Churchill County, NV (Fallon Naval Air Station). Similar predictions were made for St. Mary's County, MD, (Patuxent NAS), where chaff releases contribute no more than 0.008% of the total particulate matter emissions. Currently, the US Navy is sponsoring studies to determine chaff air concentrations at ground level of training ranges and housing areas located at Fallon NAS. Preliminary results indicate that chaff plumes comprise less than 0.5% of the particulate matter present at these sampling areas.

Several investigations have demonstrated that Al-coated dipoles are resistant to weathering and breakdown under desert conditions. A 1977 US Navy-sponsored a study found no evidence to indicate that chaff degrades significantly or quickly in water from the Chesapeake Bay nor did this material leach significant amounts of aluminum into the Bay. A recent study by our group found no evidence that 25 years of chaff operations at the Naval Research Laboratory detachment at Chesapeake Beach, MD resulted in a significant increase in sediment or soil aluminum concentrations (Wilson et al 2000). However, additional studies are needed to determine the half-life of chaff dipoles in various soils and environmental conditions and whether dipoles breakdown to respirable particles. A current study at the University of Nevada, Desert Research Institute is examining the propensity of chaff dipoles to be reduced to respirable sizes by wind-driven sand abrasion.

Human Health Effects

It has been suggested that chaff poses an inhalation hazard and may induce diseases of the respiratory tract. This idea has been addressed in detail by several groups (Hullar et al. 1999, Carpenter et al. 2000). Chaff dipoles are manufactured at diameters that are too large (~40 μM) to be inhaled into the lung. If inhaled, dipoles are predicted to deposit in the nose, mouth, or trachea and are either swallowed or expelled. Although there is no definitive evidence from the epidemiological literature that chaff exposure is not harmful, there is epidemiological information available on workers involved in the glass fiber manufacturing industry. Data from these studies suggests that exposure to fibrous glass is not associated with increased risk of death from respiratory disease.

There are reports that occupational exposure to aluminum may increase the risk of asthma (Sordrager et al. 2001, Vandenplas et al. 1998) and pulmonary fibrosis (Chip et al. 1998, Nemery 1998). We are not aware of any cases of occupationally induced asthma or pulmonary fibrosis among workers involved in the manufacture or handling of RF chaff. Intact chaff dipoles are not expected to penetrate the lungs and therefore, would not be expected to increase the risk of either asthma or pulmonary fibrosis among exposed persons. Dermal contact with RF chaff is a possible exposure scenario for sailors and ground troops during training exercises or combat. A review of historical medical records of military personnel at potential risk will be conducted in the near future. However, to date there is no data on the ability of chaff to cause dermal or ocular irritation in humans or animals. Occupational exposure to fibrous glass has been linked to eye and skin irritation and irritation of the nasal and oral mucous membranes (NIOSH 1977).

Ingestion of chaff dipoles could occur through drinking unfiltered water drawn from a source containing chaff or by swallowing fibers that become trapped in the mouth and upper airway following inhalation of chaff. Children that consume large amounts of soil (i.e., geophageous) are potentially at risk of ingesting chaff if this material is present in the soil. There are no reports of children or adults that have developed adverse health effects after ingestion of chaff. However, studies in which laboratory animals were dosed with chaff at varying doses revealed no gross or histological signs of toxicity or mechanical injury upon postmortem examination (Wilson et al. 1999)

It has been speculated for some time that Al may be associated with several neurodegenerative diseases (ATSDR 1992) and chaff dipoles are a potential source of aluminum in cases of accidental ingestion. However, the link between dietary Al ingestion and development of neurodegenerative diseases remains tenuous. Absorption of Al by the human gastrointestinal tract is minimal (<1%), with most ingested Al being passed out of the body in the feces (Jouhanneau et al. 1997). It has been shown that the bioavailability of Al from ingested chaff in both *in vitro* and *in vivo* models is considerably less than that of $Al(OH)_3$, which is a source of Al in common Al-based antacids (Wilson et al. 1999).

Health Effects on Livestock & Wildlife

The potential negative impact of chaff on wildlife and livestock health has been a major issue for the DOD since the 1950's. A number of legal claims have been filed against the USAF alleging that livestock had died from ingesting chaff while grazing (USAF 1979). Studies conducted in cattle and goats at the University of Wisconsin and found no evidence that chaff ingestion posed a significant health hazard for farm animals (USAF 1979). In similar studies, the Canadian Department of Agriculture found no evidence of toxicity in calves fed RF chaff (CDA 1972).

At least one study (USAF 1997) describes several ground surveys of two chaff use MOAs and reports that chaff debris, including plastic end caps, foil, and paper wrappers, was visible on the training ranges. Clumps of chaff from cartridges that did not deploy correctly were also observed. However, animal abundance and nesting activities of rodents or birds were considered normal. It was concluded from the results of this study that chaff interference with wildlife activities is negligible.

Chaff has also been deployed over estuarine environments, several federal agencies have commissioned studies of the effects of chaff on these ecosystems. Multiple marine organisms, including benthic polychaetes, American oyster, blue mussel, Blue crab, filter-feeding menhaden, and killifish, were utilized in studies investigating the impact of chaff on organisms in the Chesapeake Bay and found no evidence that RF chaff was acutely toxic to any of the species tested. Concentrations of chaff used in these studies were described 10 to 100 times the exposure level expected to be found in the Chesapeake Bay.

Degradable Chaff

Recently, the U.S. Navy considered developing chaff that could be quickly degraded (GAO 1998). One candidate under consideration for use as training chaff consisted of Al-coated degradable glass fibers. Contact with water results in degradation of the fiber. However, problems with incomplete degradation and lack of evidence that chaff is harmful to the environment resulted in suspension of further development of a degradable chaff in 1999.

Discarded styrene dispenser pistons and endcaps are visible to the human eye and account for about 95% of the total mass of product released to the environment during chaff deployment. As such, the Navy is considering the use of chaff dispenser pistons and endcaps constructed with biodegradable polymers. This program is in its preliminary stages and studies are now on-going at the Naval Research Laboratory and Naval Health Research Center Toxicology Detachment to identify biodegradable materials with little potential for ecotoxicity. The Navy plans to field biodegradable chaff dispensers and endcaps by FY 2003.

The Future of Chaff

Any military pilot will tell you the importance of chaff. This material, usually dispersed a couple handfuls at a time during an ever shrinking window of time often no greater than seconds, means the difference between the loss of life and destruction of a multi-million dollar aircraft in air-to-air combat and survival. Split second timing while executing a number of operations at Mach speed can only be acquired by training. Chaff, its composition and its use in training, has changed dramatically over the past few decades. The changes have resulted from research advances and an appreciation for potential environmental impacts of military activities. While dramatic advances in chaff are not anticipated, it use in training and combat will continue for the foreseeable future.

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Figure 1. Radio frequency chaff cartridges (Air Force version RR-188/AL, top; Navy version RR-144/AL, bottom) and chaff fibers (right). Fibers of different lengths can be seen in the Navy operational version (clear cylinder). These lengths correspond to the frequency modes of the radar spectrum. In training, however, cartridges containing only 1.8 cm fibers are used (not shown).

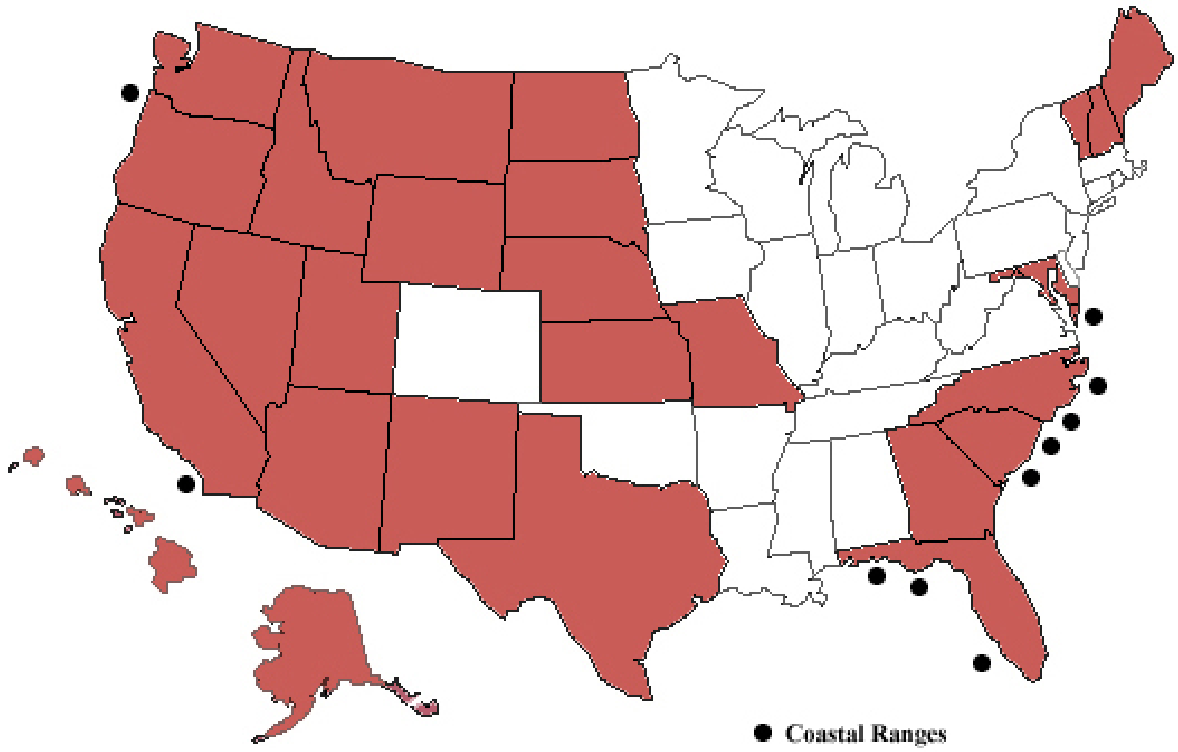

Figure 2. Chaff is used in training over ranges in 26 states, 1 territory, and 10 off-shore areas encompassing approximately 2.7 million square miles (dark shaded states). Coastal ranges estimated at 400 mi^2 each. Figure is adapted from the GAO report (1998).